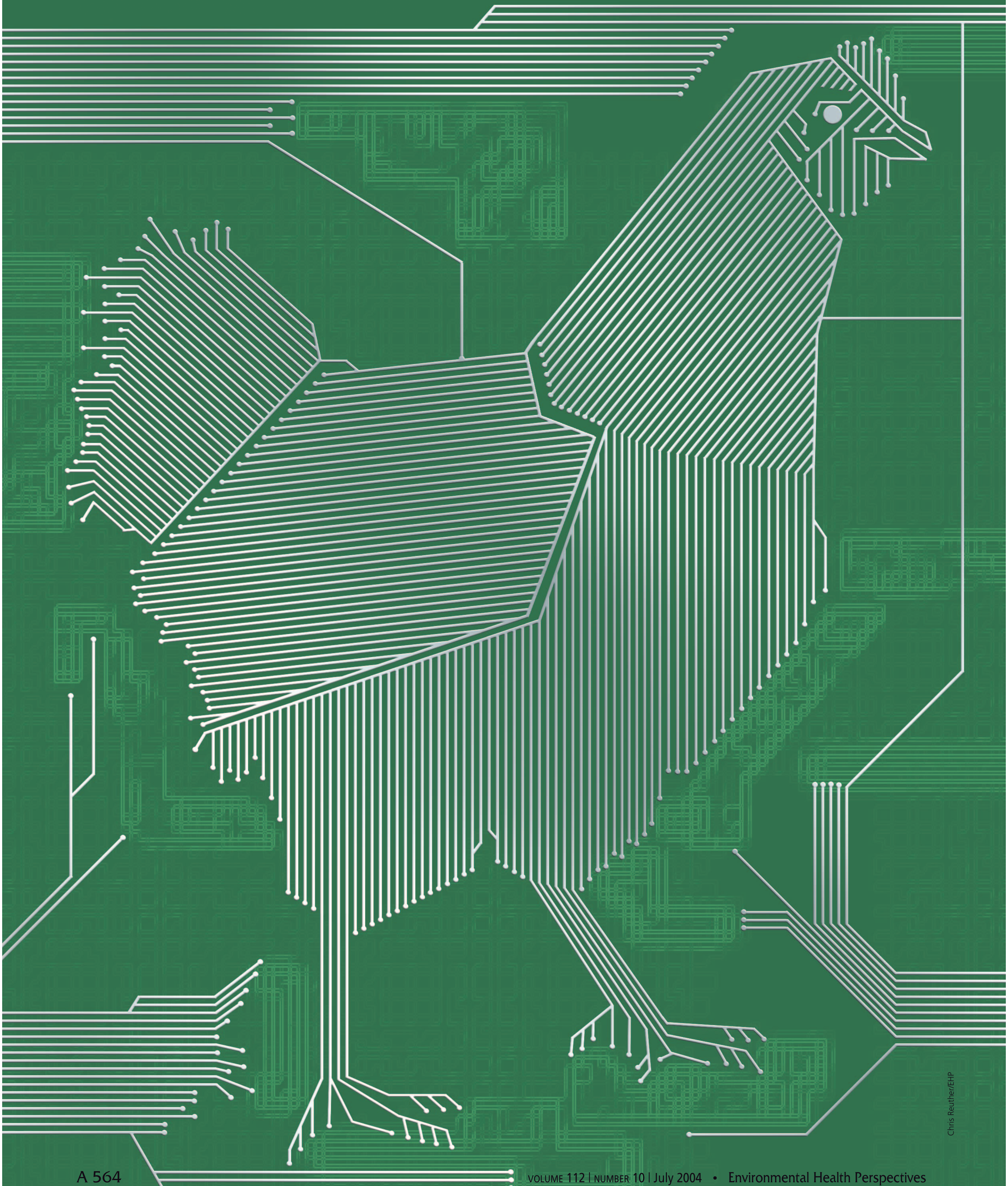


Chris Reuther/EHP

Chicken Electronics

A Technology Plucked from Waste

The 8 billion–plus broilers produced each year by the U.S. poultry industry leave behind some 3 billion pounds of waste feathers. Traditional disposal strategies are less than perfect. Feathers can be processed into a low-grade animal feed, but this demands water and energy. They also can be incinerated or buried, which involves storage, handling, and, for incinerated feathers, emissions control and ash disposal. Richard Wool, director of the Affordable Composites from Renewable Sources (ACRES) program at the University of Delaware, believes he's found a way to use these feathers that kills two birds with one stone, so to speak. Wool's solution is a collaboration with poultry giant Tyson Foods to explore manufacture of another resource-depleting necessity—the circuit board—using chicken feathers.

A New Breed of Circuit Board

In its simplest form, a circuit board is a thin sheet of plastic with a glued-on layer of copper foil. Excess foil is removed, usually by a chemical etching process, and components are attached to the remaining foil. Dave Jones, an associate director in the Waste Management Division of the U.S. Environmental Protection Agency's Region 9 offices, says there are both manufacturing and end-of-life issues to be considered: "You have the issue of the consumption of copper and petroleum products to begin with, and anytime you're dealing with the extraction and use of virgin resources, you have the potential for incredible environmental impact," he says. "Then you have to consider what's added to the petrochemical product to make the board—typically something like chlorine."

When a circuit board reaches the end of its life, it's typically taken to a smelter, says Jones. There, the metals are recovered and the plastic burned. "I think anytime we can find a way to preclude the need to use new resources, we're better off on many levels," he says.

When you're dealing with signals sent within a computer, speed is critical, but electricity is a finicky thing, and easily distracted. In a phenomenon Wool refers to as "electron rubbernecking," the negatively charged electrons can easily be lured down side streets if a material carrying too great an attractive charge is nearby (a situation further complicated by the diminishing size and increasing proximity of the components that end up on the circuit board). Wool's goal, then, was to find something noninteractive to serve as the basis for a new breed of circuit board.

He also, he says, wanted something "light, yet strong, and with as much air involved as possible. Feathers are extremely light, and they're hollow, yet very strong. That makes them ideal." Feathers are made of the protein keratin, which in fiber form is both light and tough enough to withstand mechanical and thermal stresses. The hollow fiber is of very low density, providing strength without sacrificing weight.

Wool arranged a collaboration in which Tyson would provide waste feathers for experimentation. Tyson washed the feathers and stripped the quill material away, leaving behind the air-filled down, which the company pressed into thin mats.

Wool coated the keratin fiber mats with two different commercial soybean oil preparations in several different proportions. The resulting boards were tested for qualities including rigidity and wetting (the fibers must be saturated by the soybean resin to achieve the desired dielectric constant), as well as vibration damping and thermal expansion, physical performance attributes important in applications including electronic, automotive, aerospace, defense, and farming equipment.

The best end product so far, using 30% keratin by weight, has a lower dielectric constant than conventional semiconductor insulator materials such as silicon dioxide or polyimides. For comparison, Wool says, whereas the dielectric constant of air is 1.0 and that of silicon dioxide is 3.8–4.2, keratin fibers have a dielectric constant of 1.6. That means electrons can move on the feather-based printed circuit boards at twice the speed as traditional circuit boards.

The new circuit boards also had enough strength and rigidity to satisfy industrial requirements, and a coefficient of thermal expansion similar to silicon dioxide and polyimides. "That's important," Wool explains, "because a high thermal expansion coefficient can damage printed circuits and lead to brittleness and durability issues. Air has a very high thermal expansion coefficient, but an unexpected sidelight of this process is that the air merely expands out of the keratin fiber, giving you almost a convective cooling effect." Wool presented these findings 2 June 2004 at the 11th European Conference on Composite Materials in Rhodes, Greece.

A Side Order of Soybeans

The soybean resins Wool used are based on the oil's natural makeup of triglycerides: three fatty acids joined at a glycerol juncture. "Through fairly common refining techniques, we can get the fatty acid distribution desired," he says. "Then, in another simple, low-temperature process, we treat the oils with hydrogen peroxide and formic acid, and then add acrylic acid to get the characteristics we want. The advantage to triglycerides is that they have positive, negative, and neutral groups, so they can adhere to almost anything as a substrate."

Ideally, says Wool, you'd want to be able to grow the exact fatty acids desired in the field, without any modification. "That's certainly well within the capabilities of modern genetic engineering," he says. "In fact, we've already done that with a patented pressure-sensitive adhesive we created."

Wool points out that all epoxide preparations use dangerous intermediates such as formic acids. "The [positive] environmental impacts [of this process] derive from the reduction in use of fossil fuels and related global warming gases through utilization of carbon dioxide by photosynthetic growth in the field," he says. And once again, the dielectric constant comes into play: the dielectric constant of the current industry standard for circuit board epoxies, a composite known as FR4, can range from 3.9 to 4.8, depending on the manufacturer.

Wool estimates a manufacturer would require about 200 million bushels of soybeans to make enough epoxy to keep up with Tyson's 2 billion pounds of chicken feathers. But that would be a drop in the bucket compared to soybean production in the United States, estimated by the U.S. Department of Agriculture (USDA) at nearly 3 billion bushels for 2003.

Wool is careful to point out that biobased products such as this soybean resin are not necessarily less expensive to produce. "Biobased is generally less energy-intensive," he says. "There are exceptions like ethanol, which takes a lot of energy to make. But in general, biobased uses less water and energy than petroleum-based."

The bottom line, says Wool, is that we're running out of petroleum. As we do, the need grows to replace those resources with plant alternatives, which are more environmentally benign on many levels, as well as renewable. "And many of the oils are easily biodegradable at end of life for the product, which lessens the environmental impact on the other end," he adds.

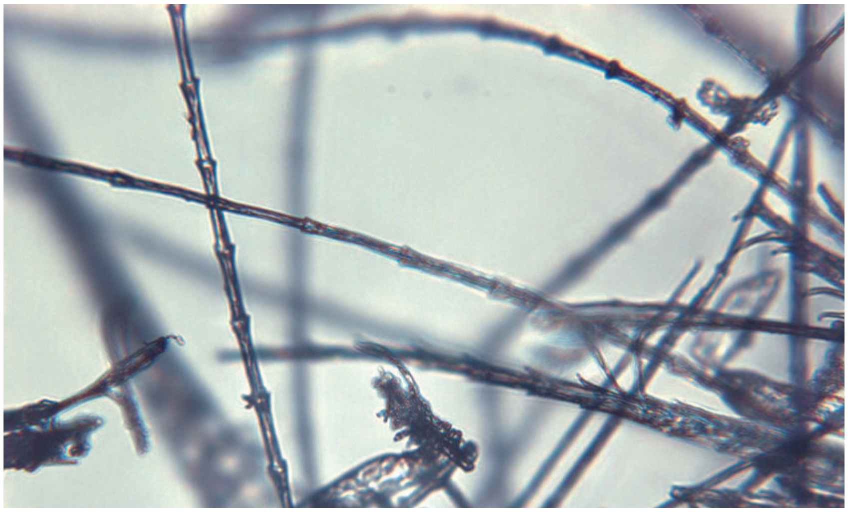
Joe Valbuena/USDA

The weighty issue of feathers. More than 8 billion broilers are produced in the United States annually, yielding approximately 3 billion pounds of waste chicken feathers.

Henny Penny: The Economics Angle

Given the differences between keratin-based circuit boards and traditional ones, Jones notes that it will be necessary to conduct many comparative studies to determine the overall improvement. "How much energy is required to power the process that makes each type of board?" he asks. "How many and what kind of acids and other chemicals are used? How much water is required? How much pollution is generated by each one? All of these questions have to be addressed before you can proclaim one process superior to any other."

Chavonda Jacobs-Young is a national program leader in the National Research Initiative Competitive Grants Program at the USDA Cooperative State



The low-down on feathers. A micrograph of feathers (above) shows hollow keratin fibers, a light, tough material. These fibers are combined with a soy-based epoxy to make printed circuit boards (right) that are not only recyclable but also faster than conventional boards.

C. K. Hong and R. P. Wool/University of Delaware

Research, Education, and Extension Service. She says Wool's research falls under her department's purview in that, while helping U.S. farmers become more competitive globally, it could also allow for the development of a value-added product that not only avoids the use of nonrenewable resources, but also provides a constructive, environmentally sound use for something that has to date been little more than a waste product that needs to be managed.

"Replacing traditional materials with biobased materials can have a positive impact on several fronts," she says. "It can increase our national security by decreasing our reliance on foreign [oil] resources, and it can increase the viability of the farming industry in this country. And anytime you can convert what is normally a waste into an end-user product, that can only have a positive environmental impact."

Circuit board industry consultant John Fisher says the industry is endeavoring to progress in a "green" direction on several fronts, including moving away from lead solders and developing halogen-free laminates. But there are a variety of factors that have to be taken into account. "The first factor in any new development will be cost, because with the rise in offshore competition, this has become an increasingly cost-competitive industry," he says. "The other factors are the green aspects, and the electrical and mechanical properties. If someone comes up with something that impacts any of these criteria, it's going to find a ready market in certain segments."

For example, he explains, the low-end market—comprising televisions, washing machines, and similar products—are most interested in cost. "These users are working to take pennies out of their cost, so economics is a big driver," he says. The high-end market, on the other hand, is more interested in electrical and mechanical properties. Meanwhile, environmental aspects are an umbrella of concern for the whole industry.

Will Chicken Electronics Fly?

What Wool says is needed next is an electronics manufacturer that is willing to see if the technology will fly—something that could be on the near horizon. "Things are at the stage at the moment where I can't identify the manufacturer, beyond saying that it's one of the world's largest," Wool says. "Right now, we have a proposal pending before the USDA to sponsor further research in collaboration with this manufacturer. We expect to hear from the USDA in about two months, and in the interim, this chip manufacturer is running some of its own process tests, to check for durability under high temperature processing, determine dielectric constant and loss factors, and [look into] other issues related to manufacturing processes."

There are also still a few critical issues to be addressed, including the design and formulation of the soybean resin, to make sure it has the correct dielectric loss properties at the frequencies used by computers. And Wool is further modifying and refining the materials and processes used to make the circuit boards, for optimized electronic capabilities.

"Electronic materials aren't going to go away," Wool says. "Fossil fuels are going to go away, and because this is such an energy-intensive business, it falls to us to be able to do more with less energy. We have no choice but to minimize waste and maximize energy efficiency in every process, and this is one step in that area."

Lance Frazer

Suggested Reading

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